XXI. *An Attempt to explain a Difficulty in the Theory of Viſion, depending on the different Refrangibility of Light. By the Rev.* Nevil Maſkelyne, *D. D. F. R. S. and Aſtronomer Royal.*

Read June 18, 1789.

THE ideas of ſight are ſo ſtriking and beautiful, that we are apt to conſider them as perfectly diſtinct. The celebrated EULER, taking this for granted, has ſuppoſed, in the Memoirs of the Royal Academy of Sciences at Berlin for 1747, that the ſeveral humors of the human eye were contrived in ſuch a manner as to prevent the latitude of focus ariſing from the different refrangibility of light, and conſiders this as a new reaſon for admiring the ſtructure of the eye; for that a ſingle tranſparent medium, of a proper figure, would have been ſufficient to repreſent images of outward objects in an imperfect manner; but, to make the organ of ſight abſolutely complete, it was neceſſary it ſhould be compoſed of ſeveral tranſparent mediums, properly figured, and fitted together agreeable to the rules of the ſublimeſt geometry, in order to obviate the effect of the different refrangibility of light in diſturbing the diſtinctneſs of the image; and hence he concludes, that it is poſſible to diſpoſe four refracting ſurfaces in ſuch a manner as to bring all ſorts of rays to one focus, at whatever diſtance the object be placed. He then aſſumes a certain hypotheſis of refraction of the differently refran-

refrangible rays, and builds thereon an ingenious theory of an achromatic object-glafs, compofed of two menifcus glaffes with water between them, with the help of an analytical calculation, fimple and elegant, as his ufually are.

He has not, however, demonftrated the neceffary exiftence of his hypothefis, his arguments for which are more metaphyfical than geometrical; and, as it was founded on no experiment, fo thofe made fince have fhewn its fallacy, and that it does not obtain in nature. Moreover, which is rather extraordinary, it does not account, according to his own ideas, for the very phænomenon which firft fuggefted it to him, namely, the great diftinctnefs of the human vifion, as was obferved to me, many years ago, by the late Mr. JOHN DOLLOND, F. R. S. to whom we are fo much obliged for the invention of the achromatic telefcope; for the refractions at the feveral humors of the eye being all made one way, the colours produced by the firft refraction will be increafed at the two fubfequent ones inftead of being corrected, whether we make ufe of NEWTON's or EULER's law of refraction of the differently refrangible rays.

Thus EULER produced an hypothetical principle, neither fit for rendering a telefcope achromatic, nor to account for the diftinctnefs of the human vifion; and the difficulty of reconciling that diftinctnefs with the principle of the different refrangibility of light difcovered by Sir ISAAC NEWTON remains in its full force.

In order to go to the bottom of this difficulty, as the beft probable means of obviating it, I have calculated the refractions of the mean, moft, and leaft refrangible rays at the feveral humors of the eye, and thence inferred the diffufion of the rays, proceeding from a point in an object, at their falling upon

upon the retina, and the external angle which ſuch coloured image of a point upon the retina correſponds to.

I took the dimenſions of the eye from M. PETIT, as related by Dr. JURIN; and, the ſpecific gravities of the aqueous and vitreous humors having been found to be nearly the ſame with that of water, and the refraction of the vitreous humor of an ox's eye having been found by Mr. HAWKSBEE to be the ſame as that of water, and the ratio of refraction out of air into the cryſtalline humor of an ox's eye having been found by the ſame accurate experimenter to be as 1 to ,68327, I took the refraction of the mean refrangible rays out of air into the aqueous or vitreous humor, the ſame as into water, as 1 to ,74853, or 1,33595 to 1; and out of air into the cryſtalline humor as 1 to ,68327, or 1,46355 to 1. Hence I find, according to Sir ISAAC NEWTON's two theorems, related at Part II. of Book I. of Optics, p. 113. that the ratio of refraction of the moſt, mean, and leaſt refrangible rays at the cornea ſhould be as 1 to ,74512, ,74853 and ,75197; at the fore-ſurface of the cryſtalline as 1 to ,91173, ,91282, and ,91392; and at the hinder ſurface of the cryſtalline as 1 to 1,09681, 1,09550, and 1,09420.

Now, taking with Dr. JURIN 15 inches for the diſtance at which the generality of eyes in their mean ſtate ſee with moſt diſtinctneſs, I find the rays from a point of an object ſo ſituate will be collected into three ſeveral foci, *viz.* the moſt, mean, and leaſt refrangible rays at the reſpective diſtances behind the cryſtalline ,5930, ,6034, and ,6141 of an inch, the focus of the moſt refrangible rays being ,0211 inch ſhort of the focus of the leaſt refrangible ones.

Moreover, aſſuming the diameter of the pencil of rays at the cornea, proceeding from the object at 15 inches diſtance,

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to be $\frac{1}{5}$th of an inch in a ſtrong light, which is a large allowance for it, the ſemi-angle of the pencil of mean refrangible rays at their concourſe upon the retina will be 7° 12′, whoſe tangent to the radius unity, or ,1264 multiplied into ,0211 inch, the interval of the foci of the extreme refrangible rays, gives ,002667 inch for the diffuſion of the different coloured rays, or the diameter of the indiſtinct circle upon the retina. Now, I find, that the diameter of the image of an object upon the retina is to the object as ,6055 inch to the diſtance of the object from the center of curvature of the cornea; or the ſize of the image is the ſame as would be formed by a very thin convex lens, whoſe focal diſtance is ,6055 inch, and conſequently a line in an object which ſubtends an angle of 1′ at the center of the cornea will be repreſented on the retina by a line of $\frac{1}{5678}$th inch. Hence the diameter of the indiſtinct circle on the retina before found, ,002667 will anſwer to an external angle of $,002667 \times 5678' = 15'\ 8''$, or every point in an object ſhould appear to ſubtend an angle of about 15′, on account of the different refrangibility of the rays of light.

I ſhall now endeavour to ſhew that this angle of ocular aberration is compatible with the diſtinctneſs of our viſion. This aberration is of the ſame kind as that which we experience in the common refracting teleſcope. Now, by computation from the tabular apertures and magnifying powers of ſuch teleſcopes, it is certain that they admit of an angular indiſtinctneſs at the eye of no leſs than 57′; therefore the ocular aberration is near four times leſs than in a common refracting teleſcope, and conſequently the real indiſtinctneſs, being as the ſquare of the angular aberration, will be 14 or 15 times leſs in the eye than in a common refracting teleſcope, which may be eaſily allowed to be imperceptible.

Moreover,

Moreover, Sir ISAAC NEWTON has obſerved, with reſpect to the like difficulty of accounting for the diſtinctneſs with which refracting teleſcopes repreſent objects, that the erring rays are not ſcattered uniformly over the circle of diſſipation in the focus of the object-glaſs, but collected infinitely more denſely in the center than in any other part of the circle, and in the way from the center to the circumference grow continually rarer and rarer, ſo as at the circumference to become infinitely rare; and by reaſon of their rarity are not ſtrong enough to be viſible, unleſs in the center and very near it.

He farther obſerves, that the moſt luminous of the priſmatic colours are the yellow and orange, which affect the ſenſe more ſtrongly than all the reſt together; and next to theſe in ſtrength are the red and green; and that the blue, indigo, and violet, compared with theſe, are much darker and fainter, and compared with the other ſtronger colours, little to be regarded; and that therefore the images of the objects are to be placed not in the focus of the mean refrangible rays, which are in the confine of green and blue, but in the middle of the orange and yellow, there where the colour is moſt luminous, that which is in the brighteſt yellow, that yellow which inclines more to orange than to green.

From all theſe conſiderations, and by an elaborate calculation, he infers, that though the whole breadth of the image of a lucid point be $\frac{1}{55}$th of the diameter of the aperture of the object-glaſs, yet the ſenſible image of the ſame is ſcarce broader than a circle whoſe diameter is $\frac{1}{250}$th part of the diameter of the aperture of the object-glaſs of a good teleſcope; and hence he accounts for the apparent diameters of the fixed ſtars as obſerved with teleſcopes by aſtronomers, although in reality they are but points.

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The like reaſoning is applicable to the circle of diſſipation on the retina of the human eye; and therefore we may leſſen the angular aberration, before computed at 15′, in the ratio of 250 to 55, which will reduce it to 3′ 18″.

This reduced angle of aberration may perhaps be double the apparent diameter of the brighteſt fixed ſtars to an eye diſpoſed for ſeeing moſt diſtinctly by parallel rays; or, if ſhort-ſighted, aſſiſted by a proper concave lens; which may be thought a ſufficient approximation in an explication grounded on a diſſipation of rays, to which a preciſe limit cannot be aſſigned, on account of the continual increaſe of denſity from the circumference to the center. Certainly ſome ſuch angle of aberration is neceſſary to account for the ſtars appearing under any ſenſible angle to ſuch an eye; and if we were, without reaſon, to ſuppoſe the images on the retina to be perfect, we ſhould be put to a much greater difficulty to account for the fixed ſtars appearing otherwiſe than as points, than we have now been to account for the actual diſtinctneſs of our ſight.

The leſs apparent diameter of the ſmaller fixed ſtars agrees alſo with this theory; for the leſs luminous the circle of diſſipation is, the nearer we muſt look towards its center to find rays ſufficiently denſe to move the ſenſe. From Sir ISAAC NEWTON's geometrical account of the relative denſity of the rays in the circle of diſſipation, given in his ſyſtem of the world, it may be inferred, that the apparent diameters of the fixed ſtars, as depending on this cauſe, are nearly as their whole quantity of light.

In farther elucidation of this ſubject let me add my own experiment. When I look at the brighter fixed ſtars, at conſiderable elevations, through a concave glaſs fitted, as I am ſhort-ſighted, to ſhew them with moſt diſtinctneſs, they appear to

to me without ſcintillation, and as a ſmall round circle of fire of a ſenſible magnitude. If I look at them without the concave glaſs, or with one not ſuited to my eye, they appear to caſt out rays of a determinate figure, not exactly the ſame in both eyes, ſomewhat like branches of trees (which doubtleſs ariſe from ſomething in the conſtruction of the eye) and to ſcintillate a little, if the air be not very clear. To ſee day objects with moſt diſtinctneſs, I require a leſs concave lens by one degree than for ſeeing the ſtars beſt by night, the cauſe of which ſeems to be, that the bottom of the eye being illuminated by the day objects, and thereby rendered a light ground, obſcures the fainter colours blue indigo and violet in the circle of diſſipation, and therefore the beſt image of the object will be found in the focus of the bright yellow rays, and not in that of the mean refrangible ones, or the dark green, agreeable to NEWTON's remark, and conſequently nearer the retina of a ſhort-ſighted perſon; but the parts of the retina ſurrounding the circle of diſſipation of a ſtar being in the dark, the fainter colours, blue, indigo, and violet, will have ſome ſhare in forming the image, and conſequently the focus will be ſhorter.

The apparent diameter of the ſtars here accounted for is different from that explained by Dr. JURIN, in his Eſſay on diſtinct and indiſtinct viſion, ariſing from the natural conſtitution of the generality of eyes to ſee objects moſt diſtinct at moderate diſtances, and few being capable of altering their conformation enough to ſee diſtant objects, and among them the celeſtial ones, with equal diſtinctneſs. But the cauſe of error, which I have pointed out, will affect all eyes, even thoſe which are adapted to diſtant objects.

If this attempt to ſhew the compatibility of the actual diſtinctneſs of our ſight with the different refrangibility of light

light ſhall be admitted as juſt and convincing, we ſhall have freſh reaſon to admire the wiſdom of the Creator in ſo adapting the aperture of the pupil and the different refrangibility of light to each other, as to render the picture of objects upon the retina relatively, though not abſolutely, perfect, and fitted for every uſeful purpoſe; "where," to borrow the words of our religious and oratorical philoſopher DERHAM, "all the "glories of the heavens and earth are brought and exquiſitely "pictured."

Nor does it appear, that any material advantage would have been obtained, if the image of objects on the retina had been made abſolutely perfect, unleſs the acuteneſs of the optic nerve ſhould have been increaſed at the ſame time; as the *minimum viſibile* depends no leſs on that circumſtance than the other. But that the ſenſibility of the optic nerve could not have been much increaſed beyond what it is, without great inconvenience to us, may be eaſily conceived, if we only conſider the forcible impreſſion made on our eyes by a bright ſky, or even the day objects illuminated by a ſtrong ſun. Hence we may conclude, that ſuch an alteration would have rendered our ſight painful inſtead of pleaſant, and noxious inſtead of uſeful. We might indeed have been enabled to ſee more in the ſtarry heavens with the naked eye, but it muſt have been at the expence of our daily labours and occupations, the immediate and neceſſary employment of man.

I ſhall only mention farther, and obviate an objection to the diffuſion of the rays upon the retina by the different refrangibility of light. It may be ſaid, that the ocular aberration, being a ſeparate cauſe from any effect of the teleſcope, ſhould ſubſiſt equally when we obſerve a ſtar through a teleſcope as when we look at it with the naked eye; and that therefore the

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fixed ſtars could not appear ſo ſmall as they have been found to do through the beſt teleſcopes, and particularly by Dr. HERSCHEL with his excellent ones. To this I anſwer, that the ocular aberration, which is proportional to the diameter of the pupil when we uſe the naked eye, is proportional to the diameter of the pencil of rays at the eye when we look through a teleſcope, which being many times leſs than that of the pupil itſelf, the ocular aberration will be diminiſhed in proportion, and become inſenſible.